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INTERMODULATION REDUCTION IN VHF COMMUNICATIONS SYSTEMS

John E. Erickson

Rome Air Development Center
Griffiss Air Force Base, New York

September 1975

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Capt John E. Erickson

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Rome Air Development Center
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This final report describes the results of an effort to develop hardware that can be used to reduce Intermodulation Product (IMP) generation in VHF Communication Systems. The program consisted of two tasks: the development of a production prototype of an Intermodulation Reduction Device (IRD) using a cancellation technique to achieve IMP reductions, and the development of a fully distributed VHF circulator.

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PREFACE

This final report presents the results of a contractual effort to develop a production prototype of a VHF intermodulation product cancellation system. This work is a follow-on to a previous effort in which the feasibility of building such a device was established. That effort was reported on in RADC-TR-73-404, dated March 1974 (AD919 322L).

This effort was performed under contract F30602-74-C-0243 to Addington Laboratories, Santa Clara, California. The Addington Laboratories project engineer was Mr. Rodger Billings. This project was funded by the Federal Aviation Administration (FAA) under Interagency Agreement DOT-FA74WAI-413. The Project Director for the Federal Aviation Administration on this effort was Mr. Leonard Bosin. The Rome Air Development Center project officer and the author of this final report was Capt. John E. Erickson (RADC/RBCT).

ABSTRACT

This final report describes the results of an effort to develop hardware that can be used to reduce Intermodulation Product (IMP) generation in VHF Communication Systems. The program consisted of two tasks: the development of a production prototype of an Intermodulation Reduction Device (IRD) using a cancellation technique to achieve IMP reductions, and the development of a fully distributed VHF circulator.

The performance of the production prototype IRD is very similar to the performance of the laboratory feasibility device developed under a previous effort and reported on in RADC-TR-73-404, dated March 1974. These twelve units displayed insertion losses that ranged from 2.7 dB to 3.6dB (average 3.1dB) and isolations that ranged from 45 dB to 67 dB (average 53 dB) at room temperature.

Under condition of a 50-watt CW forward signal into the IRD, and an 0.1-watt CW back signal, a strong third-order intermodulation product (IMP) was observed that averaged -41 dBm at room temperature. This IMP level is an 11-dB improvement over the -30 dBm that would typically be generated by a VHF lumped-element circulator and 41-dB improvement over the 0-dBm that is typically generated by an unprotected transmitter under similar operating conditions.

The VHF-distributed circulator displayed characteristics considerably better than a similar VHF lumped circulator (such as the circulators used

in the IRD). This circulator had a maximum insertion loss of .35 dB and a minimum isolation of 16 dB. The IMPs were about the same as for the IRD. The disadvantages of this unit are its large size and weight but it has the advantage of simplicity.

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List of Illustrations

1. INTRODUCTION

This report addresses the problem of intermodulation product (IMP) generation in transmitters. This problem is created primarily by the nonlinearities of transmitters and the collocation of radiating antennas. The problem is illustrated in Figure 1. If a VHF transmitter is radiating a signal of 50 watts (+47 dBm) on frequency f_2, and the distance from this antenna to a collocated radiating antenna is 10 feet, then the signal f_2, is reduced by about 27 dB due to space loss before arriving at the second antenna. The second antenna receives signal f_2 (now at +20 dBm) and this signal travels down the coaxial line to the transmitter. Thus, this transmitter is exposed to its own signal of frequency f_1 at +47 dBm and the signal f_2 at +20 dBm. Since the transmitter is inherently a nonlinear device, it will produce IMPs of all orders. Of primary concern, because they are the stongest IMP signals and because they fall within the passband, are the 3rd-order IMPS. The stronger of these will be about +0 dBm for an unfiltered transmitter. If a receiver antenna is located 10 feet from the antenna of the intermoding transmitter, then this +0 dBm IMP signal will reach the receiver with a power level of about -27 dBm. If the frequency of this IMP signal coincides with the frequency to which the receiver is tuned, the ability of the receiver to detect low-level incoming signals will be seriously degraded. Sensitivities for FAA receivers used in this effort were -97 dBm. If this receiver is exposed to an IMP signal at -27 dBm, a total of 70 dB of receiver sensitivity has been lost.

An approach which has proved effective in reducing transmitter IMPs uses ferrite circulators, as shown in Figure 2. A circulator is a nonreciprocal device that allows power to pass in only one direction between any two ports. A typical three-port circulator is illustrated in Figure 3. A signal inserted at port 1 is passed to port 2, a signal inserted at port 2 is passed to port 3, and a signal inserted at port 3 is passed to port 1. It can be seen that if port 3 is terminated with an impedance matching load, then a signal inserted at port 1 will still pass to port 2, but a signal inserted at port 2 will pass to port 3 and be dissipated in the termination. Used in this manner, a circulator is called an isolator since it passes power from port 1 to port 2 but not from port 2 to port 1.

If a circulator is utilized as shown in Figure 2, each transmitter is protected from any undesirable signals that might be received by the transmitter's antenna. Thus protected, the transmitter will be exposed to only its own signal. Therefore, the nonlinearities of the transmitter can generate only harmonics of the fundamental frequency. These harmonics are far removed from the bandpass of the receivers involved and are not of serious concern.

In reality, there are limitations created by the circulators themselves on the degree of success attainable with this approach. Isolation in a circulator is the ratio (in dB) of a signal applied to the circulator's output port to that portion of the applied signal that appears at the isolated

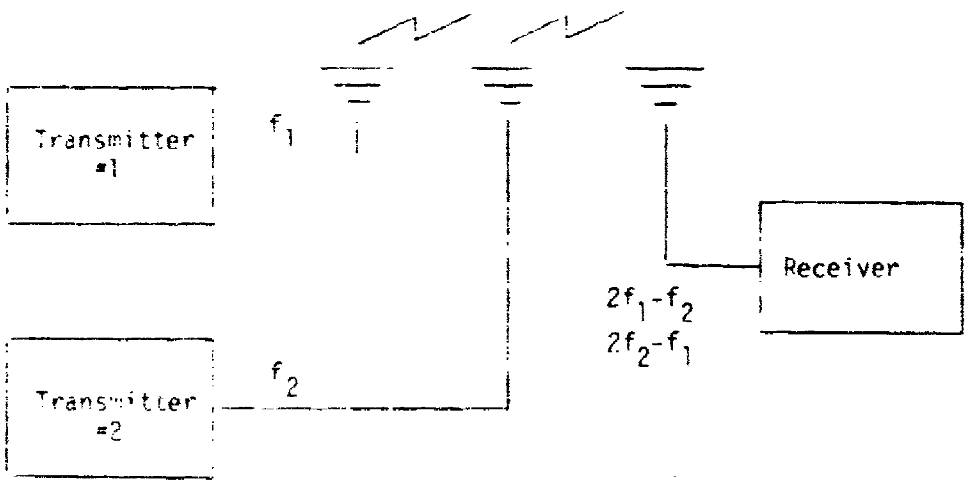


Figure 1. The Intermodulation Product Problem

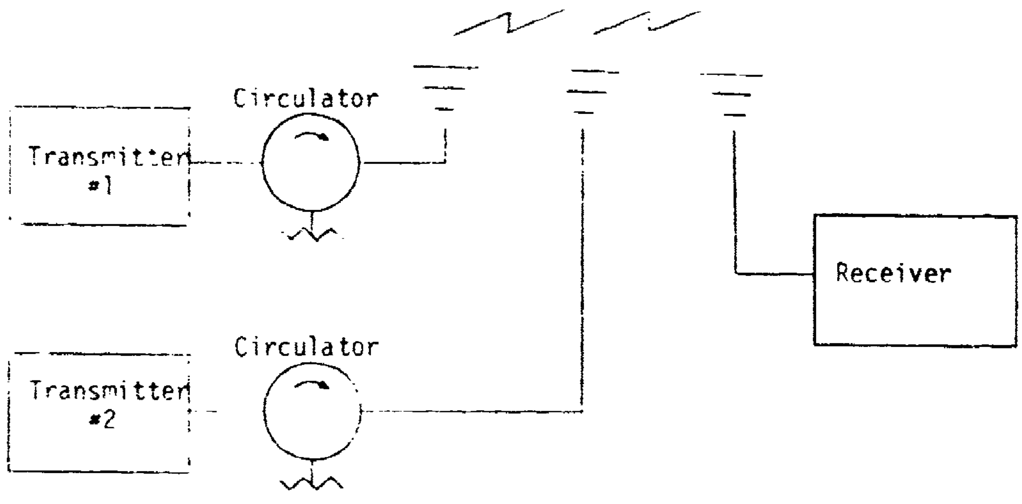


Figure 2. A Method for Reducing Transmitter IMPs

port. The degree to which the transmitter is protected from undesirable signals is a function of how much isolation the circulator provides. Another measure of performance is the insertion loss of the isolators. This is a measure of the amount of power lost in the circulator when a signal is transmitted through it in the forward direction. Insertion loss is the ratio (in dB) of power inserted at the circulator's input port to power received at the output port. Insertion loss must be kept as low as possible.

Linearity of the circulator is very important. While circulators are known to be more linear than transmitters and will therefore produce lower levels of IMPs, they still have their fundamental limitations. In a previous effort (discussed in RADC-TR-73-404, March 1974), it was found that a ferrite lumped circulator generates a strong 3rd-order IMP of -30 dBm when exposed to a forward signal of +47 dBm and a reverse signal of +20 dBm. This is an improvement of 30 dB over the 0 dBm IMP level that is generated by an unfiltered transmitter.

In the previous report, methods were identified that provide IMP reductions beyond those achievable using a single lumped circulator. A technique which uses two circulators and 90° hybrids in a manner that provides for cancellation of the strong 3rd-order IMP was tested and proven to be effective. A laboratory prototype unit was designed and built that displayed an IMP that was reduced by 13 to 22 dB below the levels generated by the single circulator.

In addition, a theory was presented that indicated that a VHF fully distributed circulator would provide for lower IMP generation than a similar VHF lumped circulator. A theoretical design of such a circulator was also provided.

The purpose of the present effort was twofold. First, the IMP cancellation device using two circulators and two 90° hybrids was to be commercially packaged as a production prototype (this unit has been designated the Intermodulation Reduction Device (IRD) and will be referred to as such in the remainder of this report). By doing this, a design would be created that could be used on a production basis, a better evaluation of the IRD's capabilities would be possible, and information needed to accurately estimate large-scale production costs for the IRD would be acquired.

[illegible] second purpose [illegible] effort was to attempt to design a VHF fully distributed circula[illegible]. This attempt could help to establish the correctness of theories on IMP generation and would establish the feasibilities of building distributed circulators at VHF frequencies. Hopefully, a useful VHF distributed circulator could result which would display a high degree of linearity (low IMP).

Design specification and goals for this effort were established as follows:

Intermodulation Reduction Device

Frequency Band	118-136 MHz
Power Capability	50 watts in either direction
Maximum Size	250 cubic inches
Maximum Weight	4 pounds
Input/Output Impedance	50 ohms
VSWR	1.5 max at input
Insertion Loss	3 dB max.
Isolation	45 dB min.
IMP	-45 dBm *

Distributed Circulator

Frequency Band	118-136 MHz
Power Capability	100 watts
Input/Output Impedance	50 ohms
Insertion Loss	0.5 dB max
Isolation	20 dB min.
IMP	-50 dBm *

* Design goals to be achieved under conditions of 50 watts of forward power and 0.1 watt of reverse power.

Size and weight of the distributed circulator were to be made as small as possible.

II. DEVELOPMENT

A. The Intermodulation Reduction Device (IRD)

The IRDs developed under this effort are based on the laboratory prototype previously built. The laboratory prototype was constructed using two Addington Laboratories VHF lumped-element isolators. Each isolator consisted internally of two circulator stages. Since the isolators were sealed and not tunable during the development of the IRD, four tunable low-pass filters were used in the IRD to achieve phase tuning. A schematic of the laboratory prototype IRD is shown in figure 4.

The production prototype IRD development was based on this configuration. Since the manufacturer of the isolators, Addington Laboratories, was the contractor on this effort, it was possible to implement two improvements. First, the entire IRD was encased as an integral unit instead of requiring separate cases and connectors for the isolators. Second, since the circulator modules could be made accessible during the tuning of the unit, it was possible to eliminate the low-pass filters which were previously required for phase tuning. The resultant configuration is shown in figure 5.

The four isolators shown in figure 5 are each tuned to the 118-136 MHz frequency band. The individual isolators display 1.4 dB of insertion loss each and 25 dB of isolation each. These units were assembled as shown in figure 5 along with two 90° hybrids. The particular hybrids used in these devices were manufactured by Merrimac Research and Development, Inc., model no. QHF-2-.130G. These units display 0.3 dB of insertion loss and maintain specified amplitudes within 0.4 dB and phases within 2°. Since a cancellation of two signals is being attempted within the IRD, the deviations in amplitude

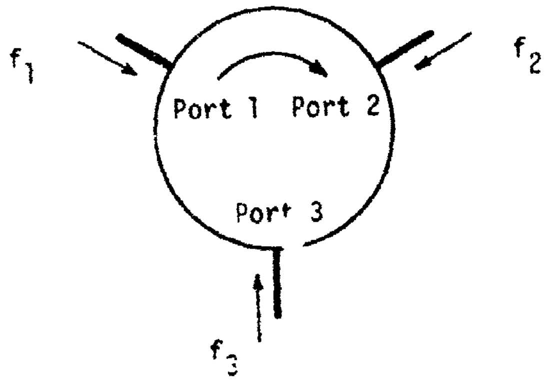


Figure 3. A Standard Three-Port Circulator

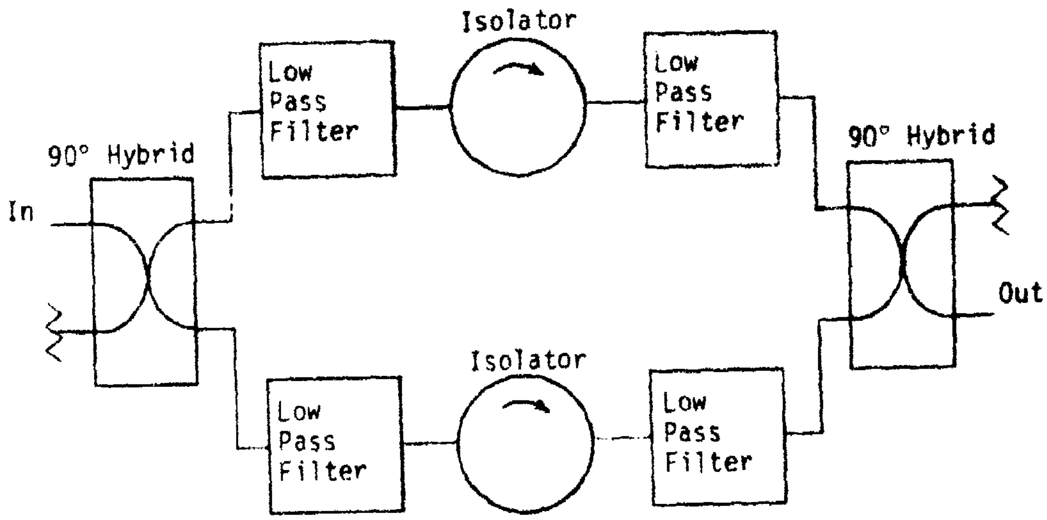


Figure 4. The Laboratory Prototype IRD

and phase in these hybrids as well as in all other components is critically important. (For a discussion of how IMP cancellation is achieved in the device, the reader should refer to Appendix B in RADC-TR-73-404, dated March 1974).

Four IRDs were built to the 4 module configuration of figure 5. The enclosure was constructed from aluminum and measures 13.20 x 6.70 x 1.49 inches with four mounting tabs that extend the length to 14.70 inches. The finished IRD (4 module configuration) weighed 7.25 pounds. The IRD enclosure was designed to satisfy the following criteria:

1. Minimize component layout complexity.
2. Minimize differences between electrical lengths in the two arms of the IRD and therefore maximize chance of achieving good cancellation.
3. Maximize the ability of the device to dissipate the heat.

During a mid-contract visit to the contractor by the RADC contract monitor, an effort was made to improve the IMP cancellation that was being achieved by the three IRDs that had been constructed at that time. Theory indicates that complete IMP cancellation is achievable under perfect conditions and an earlier laboratory experiment had produced up to 50 dB of cancellation under carefully controlled circumstances. These experiments were repeated using line stretchers in the 4-module IRD to augment phase tuning. With the line stretchers, greater than 38 dB of cancellation was observed at a fixed set of frequencies (the IMP disappeared into the noise floor). The line stretchers were then removed from the IRD and, using only the phase tuning made possible by adjusting the elements in the isolator modules, over 38 dB of cancellation

was again achieved at a fixed set of frequencies. Unfortunately, this high level of cancellation was not repeated when other frequency pairs were tested. Both the amplitude and phase of the IMP through the various components of the IRD change with frequency and this dependency destroyed the high level of cancellation when different frequencies were used.

It was resolved at this time to convert the IRDs to a 3-module configuration as shown in figure 6 instead of the 4-module configuration previously used. A severe disadvantage of the 4-module configuration was the difficulty of equalizing the electrical length in each arm of the IRD for each of the three signals involved. This problem was complicated by the fact that a phase shift is experienced by the signal as it passes through each circulator and these phase shifts are adjustable. It is necessary for input signal (f_1) at the output of the second isolator in the top arm of figure 5 to be equal in amplitude and 90° advanced in phase with respect to the portion of the input signal that reaches the output of the second isolator in the lower arm. This phase can be affected (in each arm) by both circulators. However, since the majority of the back signal (f_2) is terminated in the 2nd circulator in each arm, and since the majority of the IMP is created in the second circulator, the 2nd circulator in each arm is the only circulator that has a significant effect on the phase of f_2 or of the IMP. The result is that an ambiguous situation exists when an attempt is made to tune the 4 isolator modules of figure 5 to achieve cancellation. This ambiguity was eliminated by converting to a 3-module configuration as shown in figure 6 where there is only one isolator per

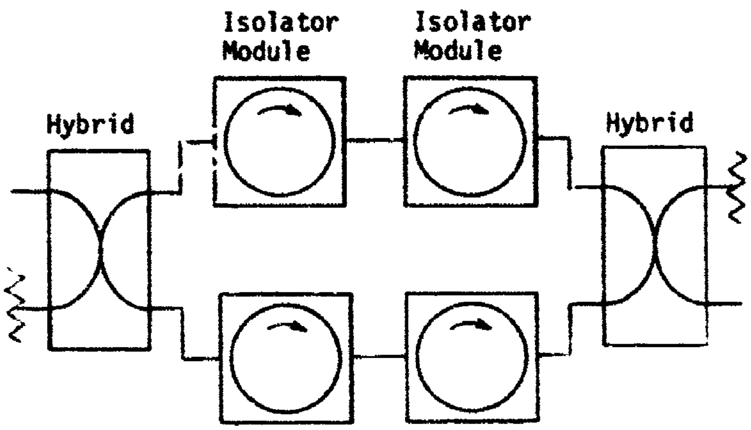


Figure 5. Production Prototype IRD - 4 Module Configuration

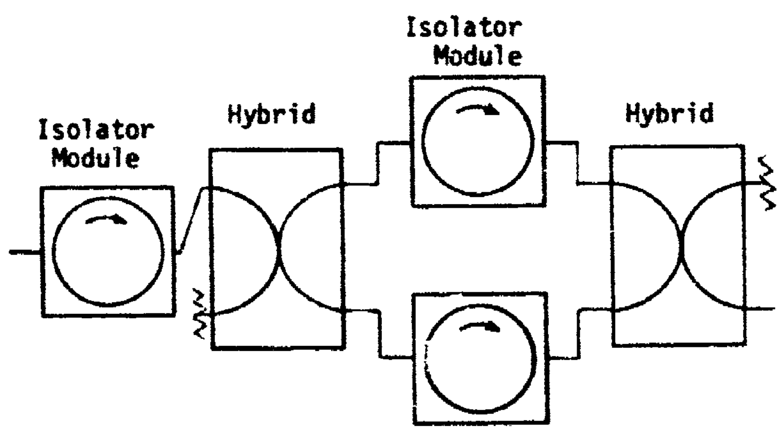


Figure 6. Production Prototype IRD - 3 Module Configuration

arm and therefore all signal phases are affected in the arm only by the adjustments to that isolator.

The 3-module configuration also has the advantage of less weight and cost. Since the enclosure design was already complete, it was used on the 3-module configuration as well. The weight savings was, therefore, only the reduction in weight due to the elimination of one ferrite module. The resulting weight for the 3-module IRD was 6.9 pounds as opposed to 7.25 pounds for the 4-module IRD. Further significant reduction in this weight and the overall size of the IRD could be realized by redesigning the enclosure for the 3-module configuration.

No sacrifice in isolation or insertion loss is required in going to the 3-module configuration. As is seen in figure 5 and 6, a signal passing in either the forward or reverse direction through the IRD must pass through two isolators in either configuration. The first isolator in the 3-module IRD must pass twice as much power as any of the remaining isolators but isolation and insertion loss are fairly constant with power changes. Therefore, since each signal passes through two isolators regardless of configuration, the 3 and 4-module IRDs will both display the same levels of isolation and insertion loss.

A new tuning procedure was implemented for the 3-module IRDs to improve cancellation by equalizing the electrical lengths in each arm of the IRD. This tuning procedure is as follows:

1. Tune individual isolator modules, using a matched magnetic field, for best VSWR, isolation and insertion loss.

2. Match the reverse phase and thru-phase of each isolator module

to that of a reference module.

3. Take IMP data in each isolator module at three frequency pairs.

4. Match together isolator modules that have the most similar IMP levels across the band.

5. Assemble the IRD using the matched modules in the parallel arms of the device.

6. Test the IRD under power and make small phase-tuning adjustments to achieve any possible further improvements in cancellation.

The thru-phase referred to in step 2 is simply the phase shift of a signal passing through the isolator module in the forward direction. The reverse phase is measured by electrically opening the input to the isolator and the internal termination of the isolator's third port. A signal is then imposed on the isolator's output port. This signal circulates once around the circulator ferrite and, since all other ports are open, reflects back into the output port. The phase of the reflected signal is compared with that of the original input and the difference represents twice the reverse phase of the isolator module.

The IMP data referred to in step 3 is taken at the following three frequency groups: $f_1 = 122$, $f_2 = 118$, $f_{IM} = 126$; $f_1 = 125$, $f_2 = 129$, $f_{IM} = 121$; $f_1 = 132$, $f_2 = 136$, $f_{IM} = 128$ (all frequencies are in MHz). This data was taken at the reduced power levels that the individual modules are expected to experience when the entire IRD is operated at full power. These power levels are $P_1 = 18$ watts and $P_2 = 0.05$ watts.

Testing showed that the 3-module IRD provides the same IMP reduction as does the 4-module IRD. The additional improvement hoped for was not

achieved. It is believed that this additional improvement is still possible if improved test equipment is used during the critical tuning phase of the IRD assembly. This test equipment would allow for swept IMP testing and is discussed in the conclusion. Although both configurations were found to provide the same IMP protection, the 3-module configuration has the advantages of smaller weight, less cost and potentially smaller size. Therefore, the majority of the IRDs were built to the 3-module configuration and it is recommended that any future IRDs acquired use this configuration.

B. VHF Distributed Circulator

A VHF distributed circulator was developed under this effort. This unit was based in part on the distributed circulator design presented in Appendix E of RADC-TR-73-404, dated 1974. The unit was redesigned by Addington Laboratories in an effort to reduce its overall size and, therefore, its total cost and weight. The distributed circulator is designed in the shape of an equilateral triangle. For the design presented in Appendix E of RADC-TR-73-404, the height of the triangle was fourteen inches and required an excessive amount of expensive ferrite material for its ferrite puck. The redesigned unit by Addington Laboratories requires a triangular height of only 8 inches which is a 40% reduction in height. A corresponding reduction in the amount of ferrite material used was achieved and, as a result, the unit's cost was considerably reduced.

The distributed circulator was first designed using G-113 ferrite material made by Trans-Tech, Inc. This circulator was assembled and tested and it performed well. Insertion loss was measured to be less than 0.4 dB across the band and isolation was greater than 16 dB across the band. With a through signal of 50 watts and a reverse signal of 0.1 watt, the IMPs were around -42 dBm which is very similar to the IMP level generated by the IRDs.

The theory indicated that a possible improvement in IMP generation might be achieved by using a G-1021 ferrite material, also made by Trans-Tech, Inc. The G-1021 material has a ferrite resonance further removed from the VHF frequency band than is the case with the G-113

material and, as a result, it was postulated that it might behave in a more linear manner. The G-1021 material also has a broader resonant linewidth than the G-113 material and, as a result, it was expected that it would exhibit a higher insertion loss. The G-1021 material has a saturation magnetization (4 πMS) of 1100 gauss verses 1780 gauss for the G-113 material.

The test results with the G-1021 material indicated, interestingly, that it generated slightly stronger IMPs then did the G-113 material (by 1 or 2 dB). It also had higher insertion losses than did the G-113 material. Insertion loss with the G-1021 material was about 0.8 dB compared to the 0.35 dB losses of the G-113 material. The only superior characteristic of the G-1021 material was the somewhat higher isolation which it displayed.

Since the G-113 material proved to be superior overall, it was used in the delivered unit.

In order to increase the isolation to the 40-dB level exhibited by the IRD, two distributed circulators would be required in series. An alternate approach, which is much less expensive, would be to configure a distributed circulator in series with a lumped-element isolator module as shown in figure 7. A single isolator module has an insertion loss of 1.4 dB and an isolation of 25 dB. By placing a module and a distributed circulator in series as shown in the figure 7, 45 dB of isolation is achieved. Since the most linear element (the distributed circulator) is closest to the antenna, it protects the isolator module from unwanted signals and therefore IMP levels remain low.

III. Equipment Operation

A. Intermodulation Reduction Device

1. Hardware description

Twelve IRDs were procured from Addington Laboratories, Inc. under this program. They have been designated "Model number 103600010, serial numbers 6099H through 6110H inclusive." Serial numbers 6099H, 6100H and 6101H were constructed in the original 4-module configuration with the remaining nine units in the 3-module configuration. Each 4-module IRD weighs 7.25 pounds and each 3-module IRD weights 6.9 pounds.

The physical dimensions of the IRDs are the same for both the 3- and 4-module configurations. These dimensions are shown in figure 8.

The top of the device is marked with an arrow indicating the proper direction of power flow. The input and output ports are also clearly labeled.

Since these IRDs have about 3 dB of insertion loss, a considerable amount of heat is dissipated internal to the unit when under continuous use. To improve the heat dissipating properties of the device, it is recommended that the IRD be mounted to a heat sinking surface if used continuously at power levels higher than 10 watts CW.

The IRDs are capable of handling 50 watts CW of power in the forward direction. Should they mistakenly be connected into the circuit backward, the IRDs will also handle 50 watts in the reverse direction for a considerable length of time. This capability is also a protection against the possibility of an opening in the output line which would cause the power to be reflected back into the IRD.

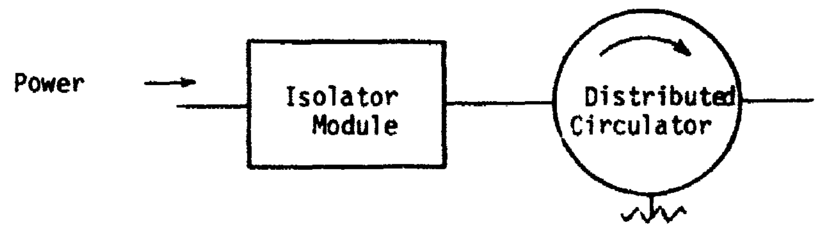


Figure 7. An Alternative Approach to Achieve Isolation

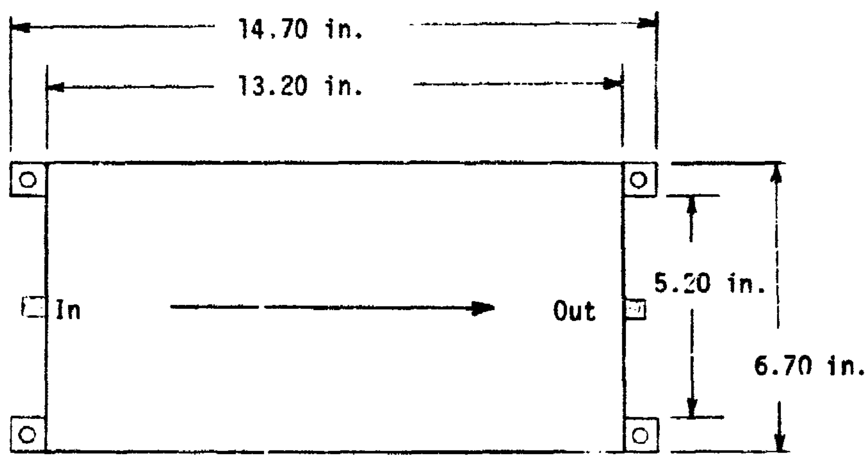


Figure 8. Intermodulation Reduction Device Dimensions

A photograph of an IRD is presented in figure 9.

2. Reliability

A failure rate of 90 per 10^6 hours of operation has been calculated by the contractor, Addington Laboratories. This equates to a mean time between failure (MTBF) of 1.1×10^4 hours.

These units are not field repairable or maintainable and the manufacturer recommends that a 10% spares level be maintained. Should a unit exhibit an insertion loss of greater than 4 dB or an isolation of less than 30 dB, a failure can be assumed to have occurred.

B. VHF Distributed Circulator

1. Hardware description

A single VHF distributed circulator was developed and built. This unit has been designated "Model number 100101775, serial number 6111H." The unit contains large magnets and should be handled accordingly. The distributed circulator weights 12.5 pounds. This circulator has three external ports that are labeled "1", "2", and "3". Any two ports can be used with the third port terminated. Circulation is from port 1 to port 2, port 2 to port 3, or port 3 to port 1. As can be seen from the data sheet in the next section, certain combinations of these ports provide better isolation than others.

The physical dimensions of the distributed circulator are shown in figure 10.

Since this device has only 0.35 dB of insertion loss, it will not be required to dissipate much heat. At 50 watts of rated power, it must dissipate 4 watts; it will do this easily since the unit is rather massive. No external heat sinking is required under normal operating conditions.

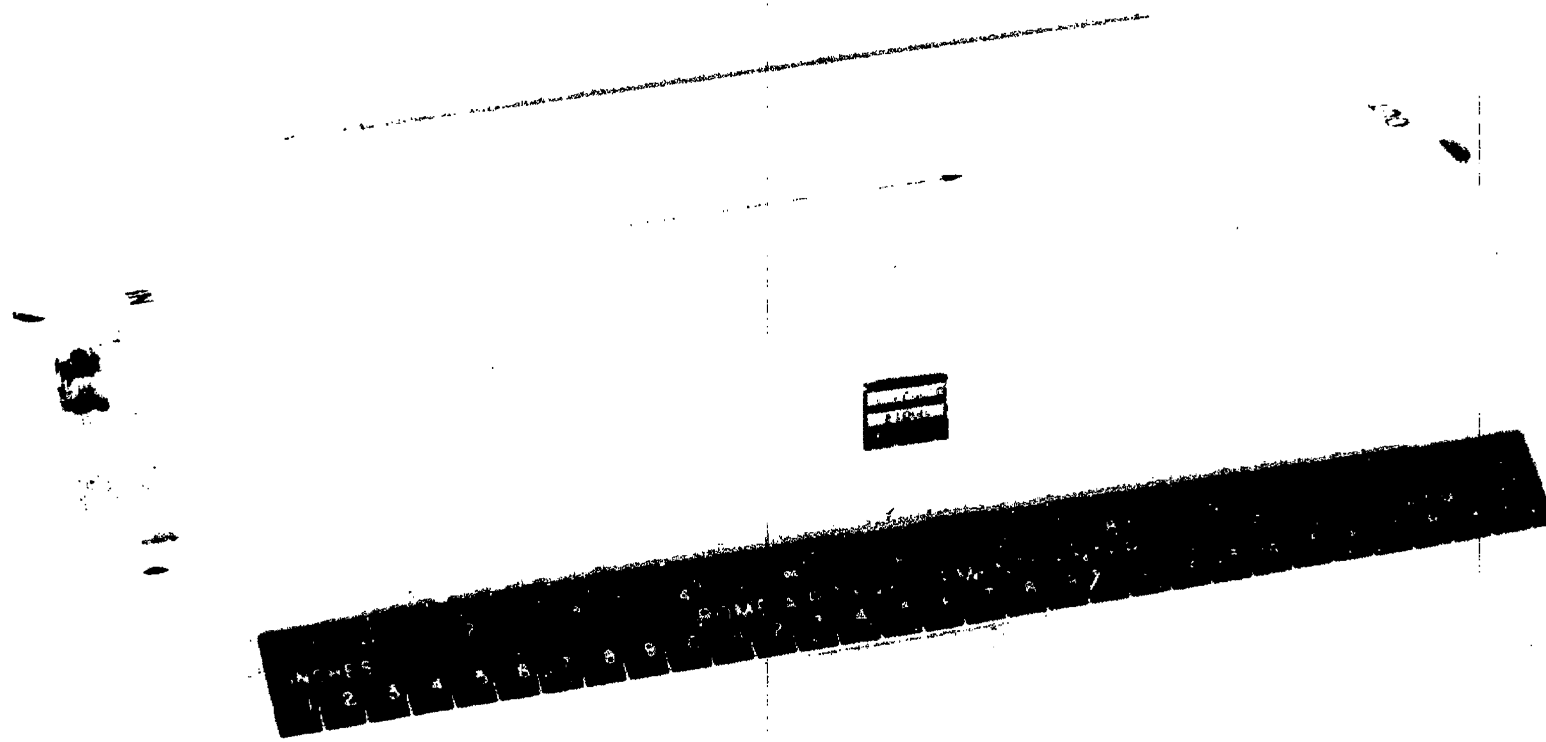


Figure 9. Intermodulation Reduction Device

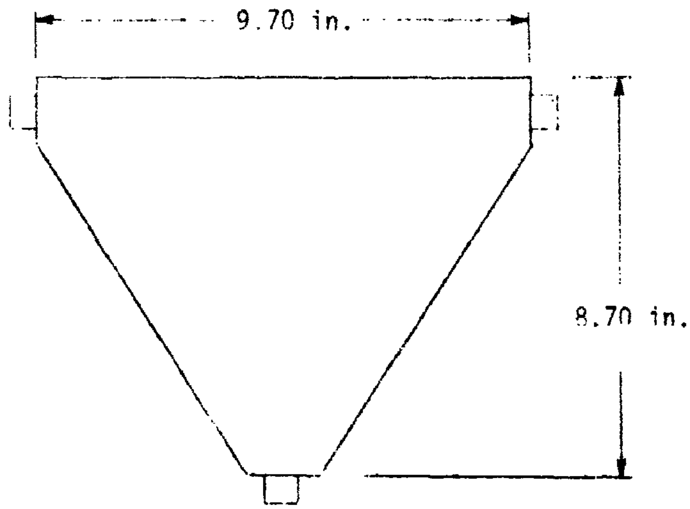


Figure 10. Dimensions of the VHF Distributed Circulator

Temperature compensation was not incorporated into this unit; thus, its operating characteristics can be expected to deteriorate as the operating temperature deviates from room temperature (+22 C). This temperature dependency can be reduced by using temperature-compensating materials in the circulator construction. Such compensation should be required for any units purchased for operational use.

A photograph of the VHF distributed circulator is presented in figure 11.

2. Reliability

The manufacturer estimates a failure rate of 20 failures per 10^6 hours of operation for the distributed circulator. This equates to a MTBF of 5.0×10^4 hours. The reliability of this unit is essentially the reliability of the ferrite material used in it. The reliability of ferrite material is more a function of the mechanical and electrical stresses to which it is exposed then it is a function of usage time.

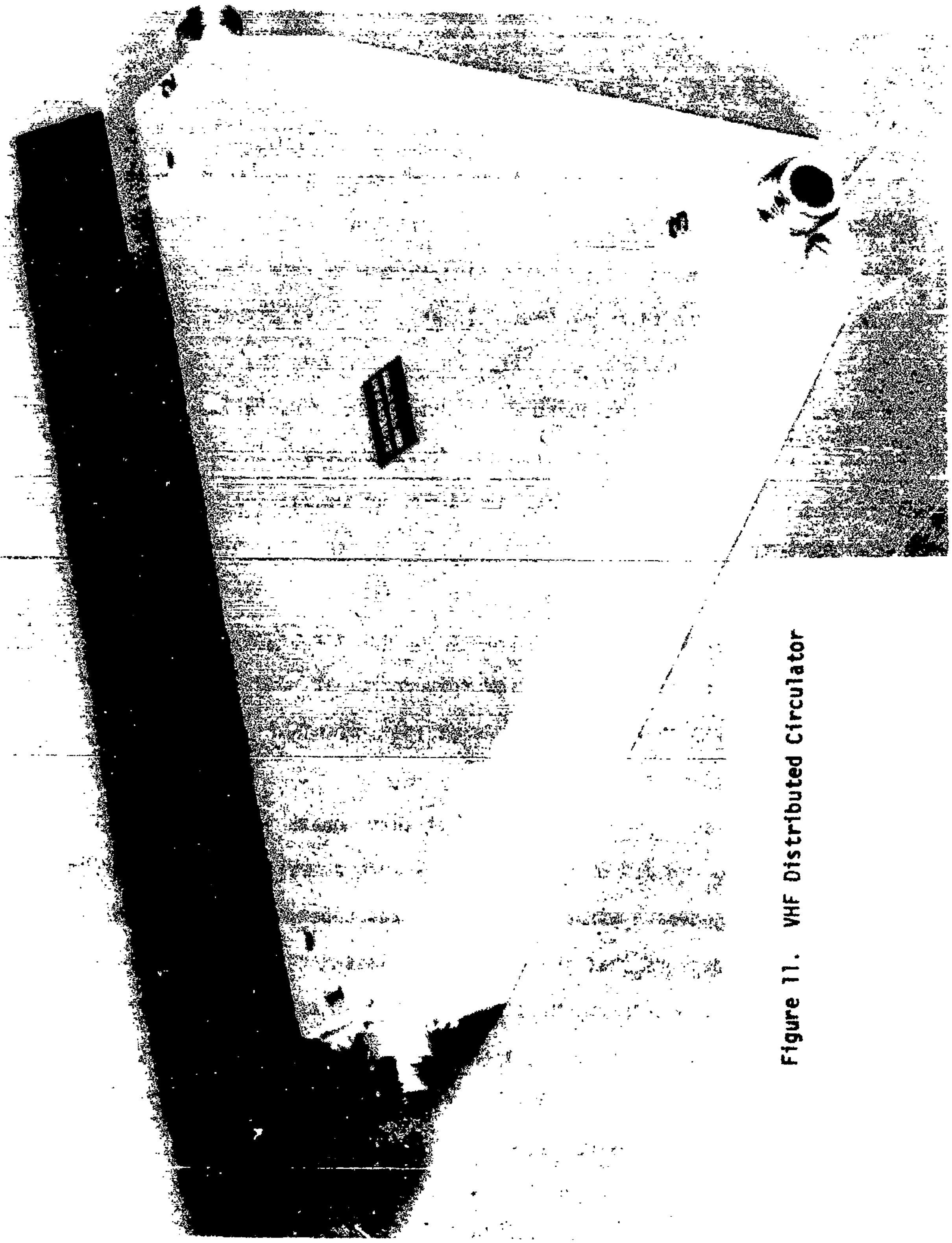


Figure 11. VHF Distributed Circulator

IV. Conclusions

A. Intermodulation Reduction Device

The Intermodulation Reduction Devices (IRDs) developed under this contract are capable of reducing all intermodulation products to the -40 dBm level when used to protect a transmitter operating at 50 watts of output power and when the unwanted signals coming from the transmitting antenna are no stronger than 0.1 watt. This is essentially the environment to which a transmitter will be exposed when there is a second transmitter, also operating at 50 watts, whose radiating antenna is located only 10 feet from the first antenna. The individual operating parameters of this device are discussed below:

Isolation: The isolation of the IRDs is greater than 40 dB across the 118-136 MHz band and at the -10°C, +22°C, and +60°C temperatures at which the unit was tested (except for S/N 6109H which dropped to 30 dB of isolation at a few frequencies at -10°C). This is sufficient isolation to reduce the IMPs of the transmitter below those of the IRD protecting it.

Insertion loss: The insertion loss of these units varied between the extremes of 2.5 dB and 4.0 dB. These losses were somewhat higher than the 3.0 dB goal. The adverse effect of these losses depends upon the power levels used. It appears that these insertion losses could be constrained to below 3.0 dB, if necessary, by the use of high-Q capacitors in the isolator modules, and by procuring a special order of ferrite with closely controlled ferrite properties. Any large-scale production should incorporate both of these improvements.

IMP Reduction: Intermodulation products were reduced to about -40 dBm on the average (under conditions of +47 dBm of forward power and +20 dBm of reverse power). IMPs were somewhat lower at higher temperatures (on the average) then at room temperature or below. The reason for this is not known, but it would appear that these units are achieving better cancellation at the higher temperature because ferrites normally generate more, instead of less, IMP as the temperature increases.

A few cases were observed where a high degree of cancellation was achieved. Examples are S/N 6101H and 6109H, both of which achieved adequate cancellation to reduce the IMP to -60 dBm at high temperature.

This effort would have been greatly aided by the existence of better test equipment in the form of an automated, swept IMP test set. Such a test set would have proved invaluable to this effort and is considered essential to further work utilizing IMP cancellation techniques. Using test hardware currently available, only one IMP frequency can be examined at a time. A lengthy and time-consuming process is required each time a new set of frequencies is selected. The difficulty of using this test set essentially precludes the possibility of achieving cancellation across a band, since the test unit must be tuned at one set of frequencies at a time, with no information available on what effect the tuning is having in the remainder of the band.

Size and weight: A significant reduction in size and weight could be achieved in these units. The established design is conservative with the primary emphasis being placed upon the need to provide equal electrical lengths in each arm of the device, to provide for isolation of each isolator module from the others and to provide adequate heat sinking of the modules. It is felt that the IRD could be reconfigured to fit in a space 2-1/2" x 3-1/4" x 6-1/2" and could be reduced in weight to 4 pounds.

Cost: It is estimated that these IRDs would cost $500 each, on a large-scale (1000 units) production basis.

B. VHF Distributed Circulator

This development is a significant addition to the arsenal of hardware available for combating IMP problems. This unit performs very well as a circulator or isolator and provides essentially the same IMP reduction as the IRD. The greatest advantage of the distributed circulator is its low insertion loss which is in the range of 0.35 dB. It is also an exceptionally reliable unit since it has very few components. The unit's isolation of about 20 dB could be improved by using two in series or by using a lumped-element isolator in series with the distributed circulator (as was previously discussed). The primary disadvantages of this unit are its size, weight and cost.

Cost: It is estimated that the VHF distributed circulators would cost $800 each, [illegible] oduction basis of 1000 or more. Similarly, the lumped-element isolator modules would cost $150 each.

V. Appendix A. Measurement Data for Insertion Loss, Isolation and VSWR

The following data was assembled by testing the twelve IRDs at Rome Air Development Center on the Hewlett Packard Automatic Network Analyzer. The measurements are made at low power (less than 0 dBm) and at room temperature (22°C). The first unit tested (serial no. 6099H) was found to be defective. This unit was returned to the manufacturer and repaired (a bad solder joint was found). The repaired unit was not available for retesting so no data on unit 6099H is included in this appendix. Unit 6110H is a typical unit and plots of its characteristics are included along with the printout.

The VHF distributed circulator was also tested and its data can be found at the end of this appendix.

INTERMODULATION REDUCTION DEVICE
MODEL 107600010
SERIAL NO. 6100H

FREQ MHZ	ISOLATION FORWARD	VSWR FORWARD	ISOLATION REVERSE	VSWR REVERSE
[illegible]	[illegible]	[illegible]	[illegible]	1.19
[illegible]	[illegible]	[illegible]	[illegible]	1.19
[illegible]	[illegible]	[illegible]	[illegible]	1.18
[illegible]	[illegible]	[illegible]	[illegible]	1.18
[illegible]	[illegible]	[illegible]	[illegible]	1.17
[illegible]	[illegible]	[illegible]	[illegible]	1.16
[illegible]	[illegible]	[illegible]	[illegible]	1.15
[illegible]	[illegible]	[illegible]	[illegible]	1.15
[illegible]	[illegible]	[illegible]	[illegible]	1.14
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	1.12
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	1.14
[illegible]	[illegible]	[illegible]	[illegible]	1.14
[illegible]	[illegible]	[illegible]	[illegible]	1.15
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

INTERMODULATION REDUCTION DEVICE
MODEL 103600010
SERIAL NO. 6101H

FREQ-MHZ	LOSS-DB FORWARD	VSWR FORWARD	ISOL-DB REVERSE	VSWR REVERSE
118.000	3.31	1.15	60.05	1.16
118.500	3.34	1.14	60.32	1.17
119.000	3.36	1.14	60.65	1.17
119.500	3.38	1.13	59.17	1.17
120.000	3.40	1.12	58.05	1.17
120.500	3.43	1.11	56.79	1.17
121.000	3.41	1.11	56.11	1.17
121.500	3.40	1.10	55.28	1.17
122.000	3.37	1.10	54.98	1.17
122.500	3.33	1.09	54.75	1.17
123.000	3.29	1.09	54.45	1.17
123.500	3.26	1.09	54.85	1.17
124.000	3.24	1.09	54.91	1.17
124.500	3.21	1.09	55.05	1.18
125.000	3.19	1.10	54.90	1.18
125.500	3.17	1.11	55.25	1.18
126.000	3.13	1.11	55.77	1.19
126.500	3.09	1.12	55.49	1.19
127.000	3.09	1.13	55.69	1.19
127.500	3.09	1.14	54.45	1.20
128.000	3.10	1.15	54.32	1.20
128.500	3.10	1.16	53.66	1.20
129.000	3.12	1.17	52.98	1.21
129.500	3.13	1.17	52.58	1.21
130.000	3.15	1.19	51.68	1.21
130.500	3.17	1.19	51.49	1.21
131.000	3.20	1.20	51.12	1.21
131.500	3.25	1.21	50.88	1.21
132.000	3.28	1.22	50.94	1.22
132.500	3.32	1.22	51.05	1.21
133.000	3.35	1.23	51.63	1.21
133.500	3.38	1.24	52.20	1.21
134.000	3.40	1.24	53.06	1.21
134.500	3.44	1.25	54.00	1.20
135.000	3.47	1.25	54.78	1.20
135.500	3.52	1.25	55.81	1.20
136.000	3.57	1.26	56.51	1.19

INTERMODULATION REDUCTION DEVICE
MODEL 103600010
SERIAL NO. 6102H

FREQ-MHZ	LOSS-DB FORWARD	VSWR FORWARD	ISOL-DB REVERSE	VSWR REVERSE
118.000	3.22	1.48	62.74	1.24
118.500	3.23	1.48	60.07	1.25
119.000	3.25	1.48	58.24	1.26
119.500	3.27	1.47	55.87	1.27
120.000	3.27	1.46	54.23	1.28
120.500	3.27	1.45	52.83	1.29
121.000	3.23	1.43	52.11	1.30
121.500	3.20	1.41	51.65	1.31
122.000	3.14	1.38	51.70	1.32
122.500	3.10	1.35	51.89	1.33
123.000	3.04	1.32	52.32	1.34
123.500	2.99	1.29	53.05	1.34
124.000	2.97	1.25	53.71	1.35
124.500	2.92	1.22	54.26	1.35
125.000	2.88	1.19	54.59	1.35
125.500	2.82	1.16	55.16	1.35
126.000	2.77	1.12	54.96	1.35
126.500	2.73	1.10	54.29	1.35
127.000	2.72	1.07	53.44	1.35
127.500	2.71	1.04	51.78	1.34
128.000	2.70	1.01	50.70	1.34
128.500	2.68	1.02	49.48	1.34
129.000	2.67	1.05	48.45	1.33
129.500	2.67	1.07	47.44	1.33
130.000	2.67	1.10	46.80	1.32
130.500	2.71	1.12	46.22	1.31
131.000	2.73	1.15	46.10	1.31
131.500	2.75	1.17	46.04	1.30
132.000	2.79	1.19	46.22	1.29
132.500	2.80	1.21	46.87	1.28
133.000	2.82	1.22	47.54	1.27
133.500	2.85	1.24	48.97	1.26
134.000	2.91	1.25	50.86	1.26
134.500	2.94	1.26	53.15	1.25
135.000	2.99	1.26	56.22	1.24
135.500	3.02	1.26	60.93	1.23
136.000	3.06	1.26	67.66	1.22

INTERMODULATION REDUCTION DEVICE
MODEL 103600010
SERIAL NO. 6103H

FREQ-MHZ	LOSS-DB FORWARD	VSWR FORWARD	ISOL-DB REVERSE	VSWR REVERSE
118.000	3.09	1.47	64.48	1.25
118.500	3.10	1.46	63.08	1.24
119.000	3.09	1.44	60.44	1.24
119.500	3.07	1.42	58.55	1.24
120.000	3.05	1.39	56.28	1.24
120.500	3.04	1.37	54.98	1.24
121.000	3.01	1.34	54.30	1.25
121.500	2.99	1.32	53.32	1.25
122.000	2.97	1.29	53.07	1.25
122.500	2.92	1.26	52.82	1.25
123.000	2.89	1.23	53.00	1.25
123.500	2.85	1.20	53.31	1.25
124.000	2.83	1.17	54.22	1.25
124.500	2.82	1.15	54.58	1.25
125.000	2.80	1.13	54.91	1.25
125.500	2.78	1.11	55.61	1.25
126.000	2.77	1.10	55.48	1.25
126.500	2.74	1.11	55.35	1.25
127.000	2.73	1.11	55.17	1.25
127.500	2.74	1.13	54.62	1.26
128.000	2.75	1.15	53.56	1.26
128.500	2.77	1.17	52.73	1.26
129.000	2.78	1.19	52.13	1.26
129.500	2.81	1.22	51.16	1.27
130.000	2.82	1.24	50.52	1.27
130.500	2.83	1.27	50.02	1.27
131.000	2.88	1.29	49.78	1.27
131.500	2.94	1.31	49.97	1.27
132.000	2.97	1.33	50.11	1.27
132.500	3.01	1.35	50.74	1.27
133.000	3.05	1.37	51.39	1.27
133.500	3.06	1.38	52.27	1.27
134.000	3.11	1.40	54.06	1.27
134.500	3.16	1.41	55.76	1.26
135.000	3.20	1.42	57.31	1.26
135.500	3.24	1.42	58.45	1.27
136.000	3.27	1.43	59.10	1.27

INTERMODULATION REDUCTION DEVICE
MODEL 103600010
SERIAL NO. 6104H

FREQ-MHZ	LOSS-DB FORWARD	VSWR FORWARD	ISOL-DB REVERSE	VSWR REVERSE
118.000	3.29	1.45	58.73	1.23
118.500	3.32	1.45	60.01	1.24
119.000	3.33	1.45	59.22	1.24
119.500	3.34	1.44	59.18	1.24
120.000	3.32	1.43	58.11	1.25
120.500	3.31	1.42	57.64	1.25
121.000	3.27	1.40	57.48	1.25
121.500	3.27	1.38	57.08	1.25
122.000	3.25	1.36	56.89	1.25
122.500	3.21	1.33	56.73	1.25
123.000	3.18	1.31	56.96	1.26
123.500	3.13	1.28	56.49	1.26
124.000	3.09	1.25	57.19	1.26
124.500	3.05	1.22	56.98	1.26
125.000	3.03	1.19	57.00	1.27
125.500	3.02	1.17	56.53	1.27
126.000	2.99	1.14	56.10	1.27
126.500	2.97	1.11	55.65	1.28
127.000	2.94	1.08	54.96	1.28
127.500	2.92	1.06	54.47	1.28
128.000	2.92	1.05	53.94	1.29
128.500	2.93	1.05	53.20	1.29
129.000	2.94	1.06	52.59	1.29
129.500	2.96	1.08	52.18	1.30
130.000	2.97	1.10	51.52	1.30
130.500	2.98	1.13	51.05	1.30
131.000	3.01	1.15	50.89	1.30
131.500	3.04	1.17	50.94	1.30
132.000	3.08	1.19	50.37	1.30
132.500	3.12	1.22	51.39	1.30
133.000	3.17	1.23	51.65	1.30
133.500	3.21	[illegible]	[illegible]	[illegible]
134.000	3.23	[illegible]	[illegible]	[illegible]
134.500	[illegible]	[illegible]	[illegible]	[illegible]
135.000	3.32	[illegible]	[illegible]	[illegible]
135.500	3.37	[illegible]	[illegible]	[illegible]
136.000	3.42	[illegible]	55.59	1.29

INTERMODULATION REDUCTION DEVICE
MODEL 103600010
SERIAL NO. 6105H

FREQ-MHZ	LOSS-DB FORWARD	VSWR FORWARD	ISOL-DB REVERSE	VSWR REVERSE
118.000	3.32	1.31	62.19	1.39
118.500	3.35	1.31	62.43	1.39
119.000	3.36	1.31	59.21	1.38
119.500	3.39	1.30	56.22	1.37
120.000	3.35	1.29	53.37	1.37
120.500	3.33	1.29	51.64	1.36
121.000	3.30	1.26	50.47	1.35
121.500	3.27	1.25	49.42	1.35
122.000	3.26	1.23	49.06	1.34
122.500	3.22	1.20	48.74	1.34
123.000	3.19	1.18	48.92	1.32
123.500	3.13	1.15	49.09	1.32
124.000	3.08	1.13	49.97	1.31
124.500	3.04	1.10	50.51	1.30
125.000	3.01	1.07	51.46	1.29
125.500	2.99	1.06	52.71	1.28
126.000	2.96	1.04	53.23	1.27
126.500	2.93	1.04	51.52	1.26
127.000	2.90	1.04	55.25	1.26
127.500	2.87	1.06	55.01	1.25
128.000	2.85	[illegible]	56.41	1.24
128.500	2.82	1.10	56.22	1.23
129.000	2.80	1.12	55.57	1.23
129.500	2.82	1.15	55.09	[illegible]
130.000	2.84	1.17	54.72	1.23
130.500	[illegible]	1.19	53.46	[illegible]
131.000	[illegible]	1.21	52.01	1.24
[illegible]	[illegible]	[illegible]	52.29	1.24
[illegible]	[illegible]	[illegible]	52.14	[illegible]
[illegible]	[illegible]	[illegible]	52.07	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

INTERMODULATION REDUCTION DEVICE
MODEL 103600010
SERIAL NO. 6106H

FREQ-MHZ	LOSS-DB FORWARD	VSWR FORWARD	ISOL-DB REVERSE	VSWR REVERSE
118.000	3.46	1.54	56.35	1.22
118.500	3.47	1.54	56.16	1.23
119.000	3.49	1.54	55.61	1.23
119.500	3.51	1.53	54.11	1.23
120.000	3.51	1.51	53.11	1.23
120.500	3.52	1.50	52.24	1.23
121.000	3.48	1.49	51.72	1.23
121.500	3.46	1.46	51.24	1.23
122.000	3.43	1.43	51.29	1.23
122.500	3.38	1.41	51.42	1.23
123.000	3.35	1.38	51.31	1.23
123.500	3.31	1.34	51.76	1.23
124.000	3.29	1.31	51.77	1.23
124.500	3.25	1.28	52.14	1.23
125.000	3.24	1.24	52.16	1.23
125.500	3.19	1.22	52.45	1.23
126.000	3.13	1.19	52.50	1.23
126.500	3.10	1.17	52.52	1.22
127.000	3.10	1.15	52.16	1.22
127.500	3.07	1.13	51.86	1.22
128.000	3.07	1.12	51.27	1.22
128.500	3.06	1.11	50.86	1.22
129.000	3.06	1.12	50.34	1.22
129.500	3.07	1.13	49.75	1.22
130.000	3.06	1.14	49.25	1.22
130.500	3.09	1.15	48.76	1.21
131.000	3.13	1.17	48.65	1.21
131.500	3.16	1.19	48.45	1.21
132.000	3.20	1.21	48.26	1.21
132.500	3.22	1.23	48.26	1.21
133.000	3.25	1.24	48.57	1.21
133.500	3.29	1.26	48.75	1.21
134.000	3.34	1.27	49.08	1.20
134.500	3.40	1.28	49.43	1.20
135.000	3.45	1.29	49.80	1.20
135.500	3.49	1.30	50.10	1.20
136.000	3.54	1.30	50.01	1.20

INTERMODULATION REDUCTION DEVICE
MODEL 103600010
SERIAL NO. 6107H

FREQ-MHZ	LOSS-DB FORWARD	VSWR FORWARD	ISOL-DB REVERSE	VSWR REVERSE
118.000	3.42	1.49	55.37	1.19
118.500	3.46	1.50	55.21	1.20
119.000	3.50	1.50	55.35	1.20
119.500	3.50	1.50	54.34	1.21
120.000	3.51	1.49	53.41	1.22
120.500	3.55	1.49	52.39	1.23
121.000	3.52	1.47	51.74	1.25
121.500	3.53	1.46	51.01	1.26
122.000	3.53	1.44	50.80	1.27
122.500	3.50	1.42	50.81	1.28
123.000	3.46	1.40	50.79	1.29
123.500	3.40	1.37	51.05	1.29
124.000	3.39	1.34	51.33	1.30
124.500	3.37	1.31	51.81	1.30
125.000	3.34	1.28	52.09	1.30
125.500	3.31	1.24	52.73	1.30
126.000	3.26	1.21	52.93	1.30
126.500	3.21	1.18	53.16	1.30
127.000	3.18	1.15	53.35	1.30
127.500	3.13	1.12	52.35	1.30
128.000	3.12	1.09	52.10	1.30
128.500	3.10	1.07	51.49	1.30
129.000	3.10	1.05	50.94	1.30
129.500	3.09	1.05	50.06	1.30
130.000	3.09	1.07	49.36	1.30
130.500	3.08	1.10	48.83	1.30
131.000	3.09	1.13	48.43	1.30
131.500	3.13	1.16	48.10	1.30
132.000	3.16	1.20	47.96	1.31
132.500	3.20	1.23	48.25	1.30
133.000	3.25	1.27	48.68	1.31
133.500	3.30	1.30	49.39	1.31
134.000	3.34	1.33	50.51	1.31
134.500	3.39	1.36	51.81	1.31
135.000	3.46	1.39	53.60	1.31
135.500	3.53	1.42	55.92	1.31
136.000	3.60	1.44	58.43	1.31

INTERMODULATION REDUCTION DEVICE
MODEL 103600010
SERIAL NO. 6108H

FREQ-MHZ	LOSS-DB FORWARD	VSWR FORWARD	ISOL-DB REVERSE	VSWR REVERSE
118.000	3.26	1.58	48.40	1.22
118.500	3.28	1.60	47.83	1.23
119.000	3.30	1.60	47.20	1.23
119.500	3.32	1.61	46.43	1.23
120.000	3.33	1.60	45.76	1.23
120.500	3.33	1.60	45.28	1.23
121.000	3.31	1.58	44.92	1.24
121.500	3.29	1.57	44.65	1.24
122.000	3.27	1.55	44.69	1.25
122.500	3.21	1.52	44.78	1.25
123.000	3.15	1.49	44.94	1.25
123.500	3.10	1.46	45.29	1.25
124.000	3.09	1.42	45.62	1.25
124.500	3.06	1.39	46.12	1.25
125.000	3.02	1.36	46.29	1.25
125.500	[illegible]	1.32	46.85	1.25
126.000	[illegible]	[illegible]	47.54	1.25
126.500	2.93	1.26	47.98	1.24
127.000	2.86	1.23	48.37	1.24
127.500	2.85	1.21	48.51	1.24
128.000	2.83	1.19	49.01	1.24
128.500	2.82	1.18	49.09	1.24
129.000	2.83	1.17	49.07	1.24
129.500	2.82	1.18	49.57	1.24
130.000	2.82	1.18	49.96	1.24
130.500	2.83	1.20	50.32	1.23
131.000	2.87	1.22	51.08	1.23
131.500	2.90	1.24	52.08	1.23
132.000	2.93	1.27	53.16	1.23
132.500	2.96	1.29	54.94	1.23
133.000	2.99	1.32	56.29	1.23
133.500	3.04	1.35	58.49	1.22
134.000	3.08	1.37	59.02	1.22
134.500	3.14	1.39	57.22	1.22
135.000	3.20	1.42	55.72	1.22
135.500	3.25	1.44	53.96	1.22
136.000	3.30	1.46	[illegible]	1.22

INTERMODULATION REDUCTION DEVICE
MODEL 103600010
SERIAL NO. 6109H

FREQ-MHZ	LOSS-DB FORWARD	VSWR FORWARD	ISOL-DB REVERSE	VSWR REVERSE
118.000	3.26	1.26	49.34	1.25
118.500	3.29	1.26	50.89	1.26
119.000	3.30	1.27	52.89	1.27
119.500	3.31	1.26	55.12	1.27
120.000	3.30	1.26	58.47	1.27
120.500	3.27	1.25	62.29	1.27
121.000	3.23	1.24	65.70	1.26
121.500	3.20	1.24	65.12	1.26
122.000	3.18	1.23	62.89	1.25
122.500	3.16	1.21	60.73	1.25
123.000	3.12	1.20	59.72	1.25
123.500	3.07	1.19	58.77	1.24
124.000	3.02	1.17	58.56	1.24
124.500	2.97	1.16	57.92	1.24
125.000	2.93	1.14	57.04	1.23
125.500	2.92	1.12	55.99	1.23
126.000	2.89	1.11	55.53	1.23
126.500	2.37	1.10	55.24	1.23
127.000	2.34	1.09	54.49	1.23
127.500	2.32	1.07	54.31	1.24
128.000	2.20	1.06	53.79	1.24
128.500	2.21	1.04	53.19	1.25
129.000	2.21	1.03	52.68	1.25
129.500	2.24	1.03	52.22	1.26
130.000	2.25	1.03	51.72	1.26
130.500	[illegible]	1.04	51.22	1.27
[illegible]	[illegible]	1.05	50.75	1.27
[illegible]	[illegible]	[illegible]	[illegible]	1.28
[illegible]	[illegible]	[illegible]	50.?1	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

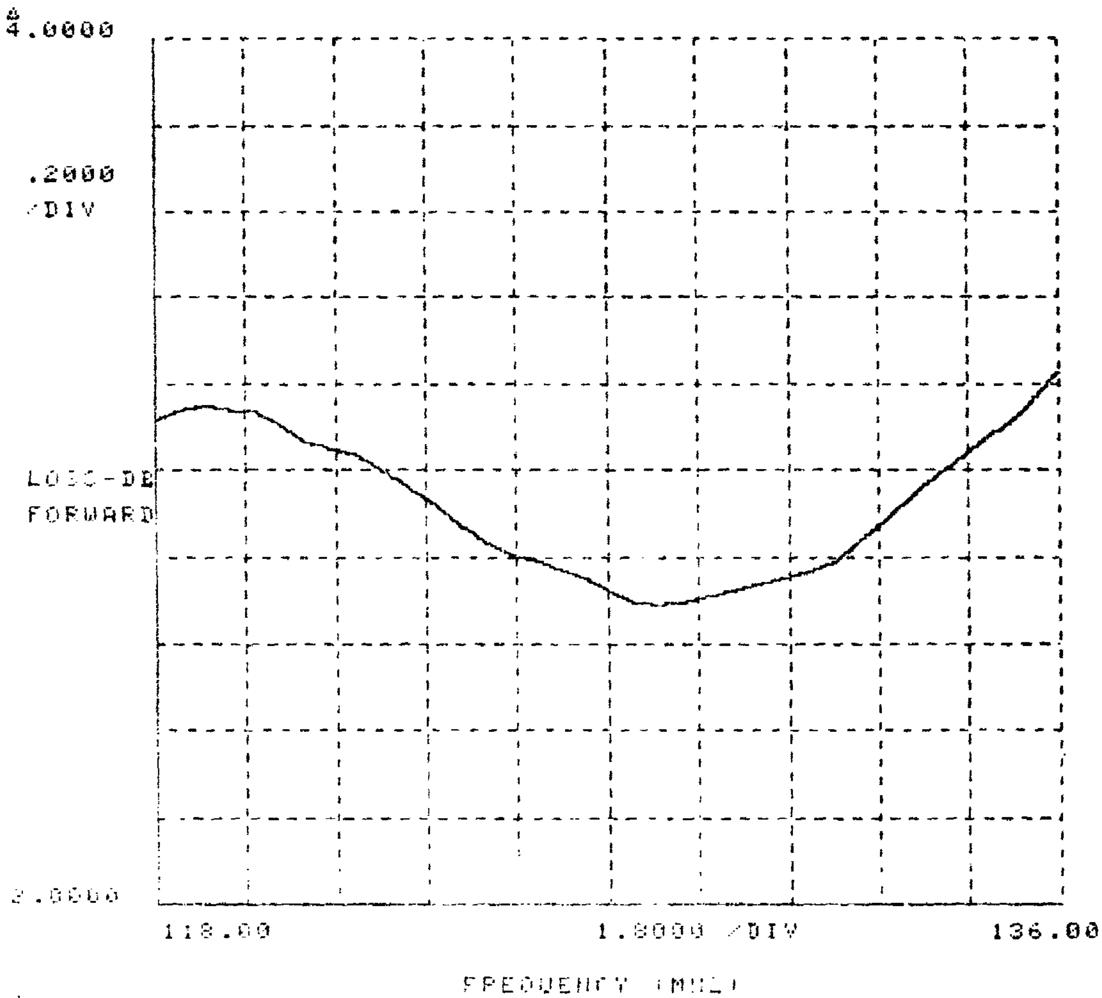
INTERMODULATION REDUCTION DEVICE
MODEL 103600010
SERIAL NO. 6110H

FREQ-MHZ	LOSS-DB FORWARD	VSWR FORWARD	ISOL-DB REVERSE	VSWR REVERSE
118.000	3.12	1.38	55.91	1.23
118.500	3.14	1.38	56.61	1.23
119.000	3.15	1.38	55.96	1.23
119.500	3.14	1.38	55.48	1.23
120.000	3.14	1.38	54.27	1.23
120.500	3.10	1.37	53.65	1.23
121.000	3.07	1.36	53.03	1.23
121.500	3.05	1.35	52.55	1.23
122.000	3.04	1.34	52.34	1.23
122.500	3.00	1.32	52.13	1.23
123.000	2.96	1.31	52.23	1.23
123.500	2.93	1.29	52.06	1.23
124.000	2.88	1.27	52.39	1.23
124.500	2.84	1.25	52.46	1.23
125.000	2.[illegible]	1.23	52.56	1.23
125.500	2.79	1.22	52.64	1.23
126.000	2.77	1.20	52.42	1.23
126.500	2.75	1.18	52.59	1.23
127.000	2.72	1.16	52.44	1.23
127.500	2.69	1.15	52.26	1.22
128.000	2.69	1.14	51.90	1.22
128.500	2.69	1.13	51.38	1.22
129.000	2.71	1.12	51.20	1.22
129.500	2.72	1.11	50.70	1.22
130.000	2.74	1.11	50.40	1.22
130.500	2.75	1.12	49.90	1.22
131.000	2.76	1.12	49.46	1.22
131.500	2.79	1.13	49.46	1.22
132.000	2.83	1.14	49.50	1.22
132.500	2.88	1.15	49.76	1.22
133.000	2.93	1.17	49.67	1.22
133.500	2.98	1.18	49.78	1.22
134.000	3.02	1.19	50.27	1.22
134.500	3.07	1.20	50.25	1.22
135.000	3.11	1.21	50.74	1.21
135.500	3.16	1.22	51.16	1.21
136.000	3.[illegible]	[illegible]	51.26	1.21

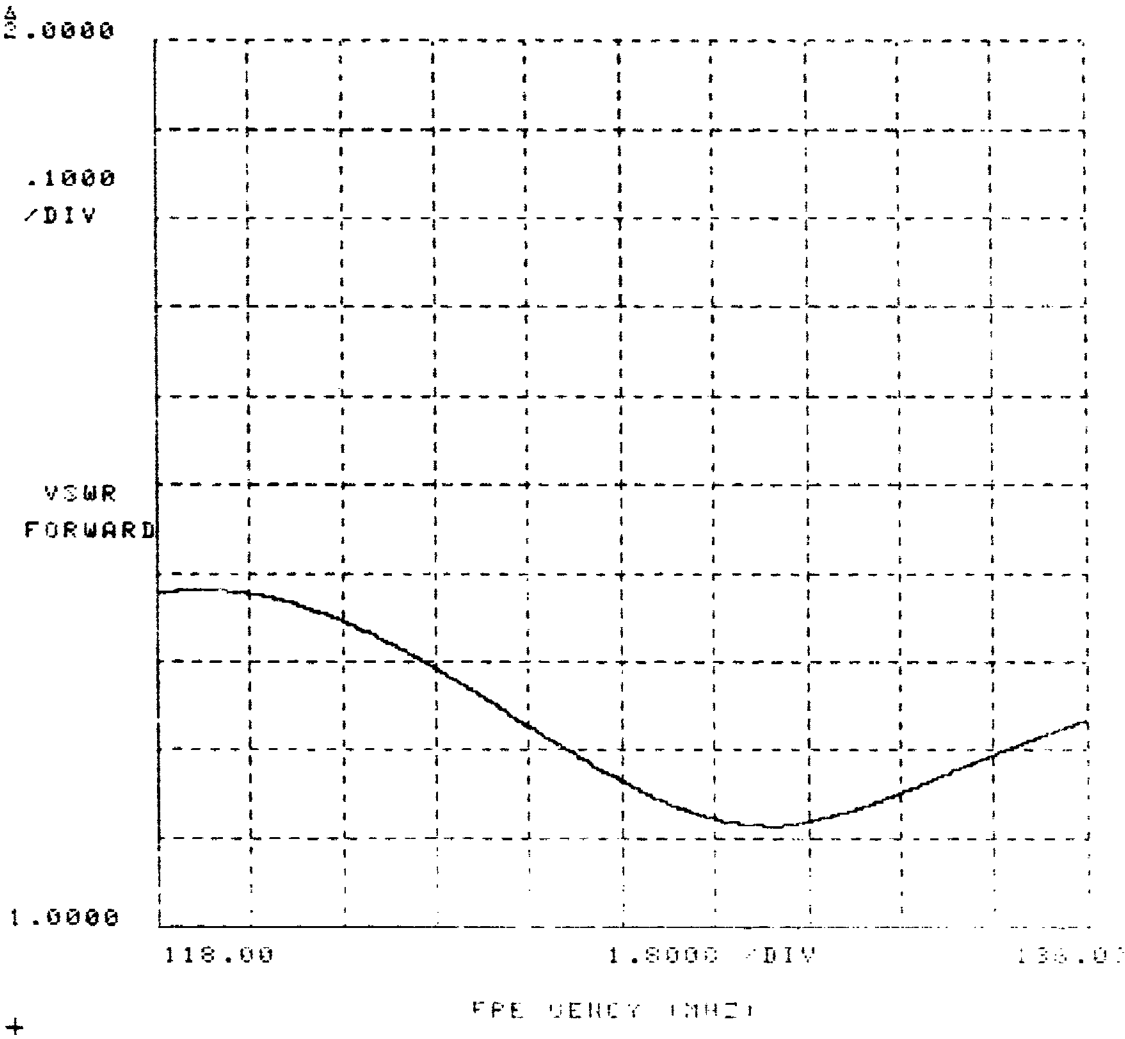
INTERMODULATION REDUCTION DEVICE

MODEL 103600010

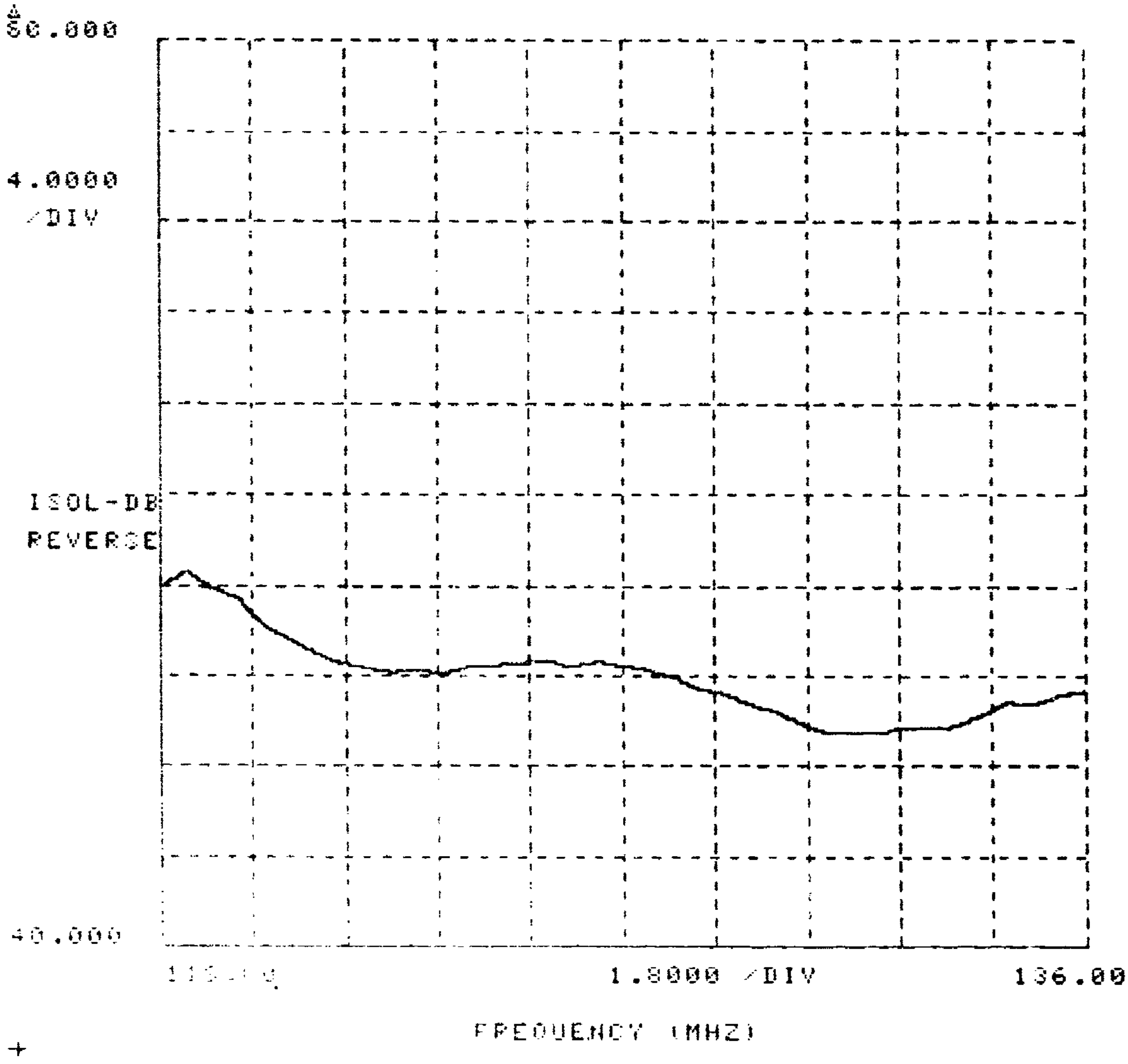
SERIAL NO. 6110H



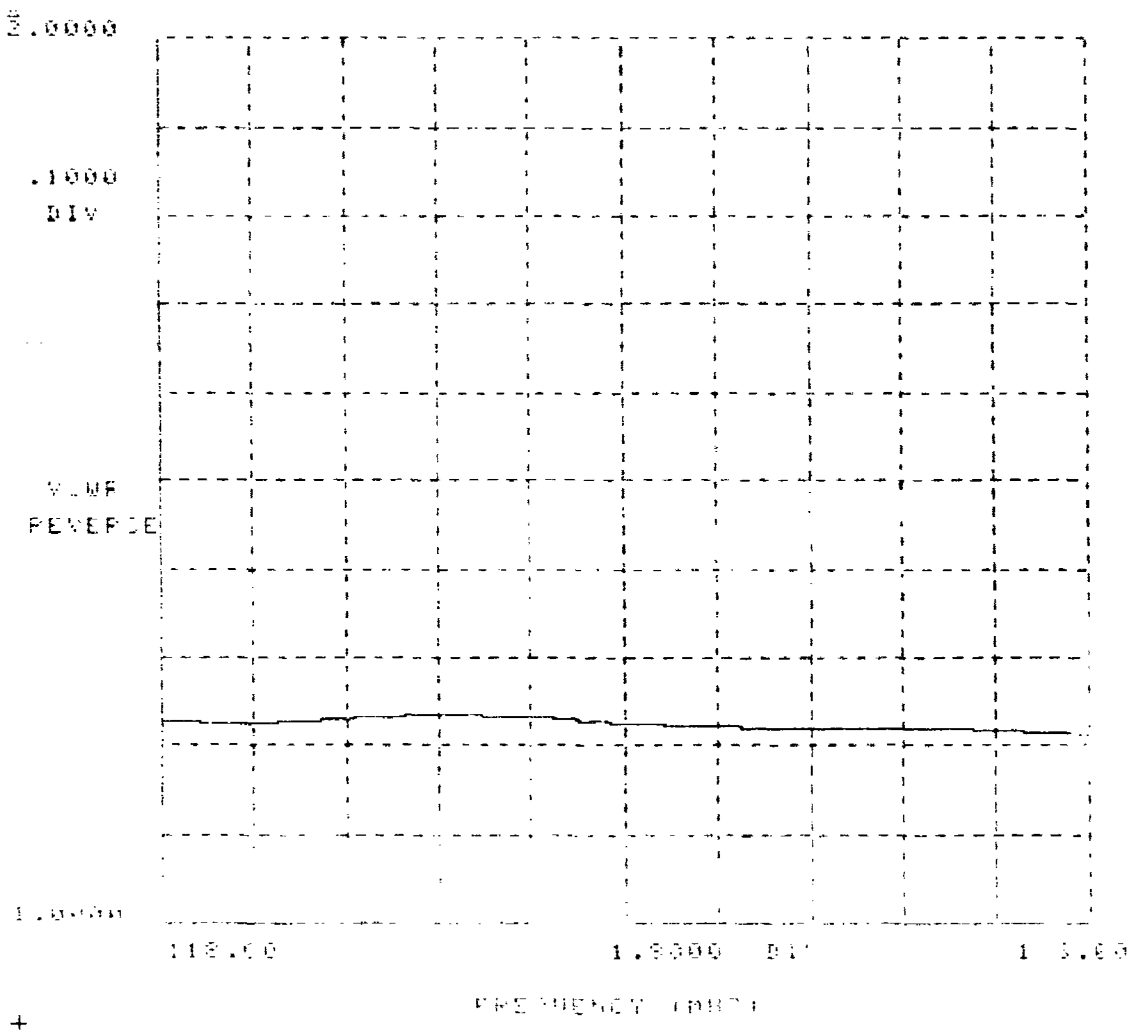
INTERMODULATION REDUCTION DEVICE
MODEL 103600010
SERIAL NO. 6110H



INTERMODULATION REDUCTION DEVICE
MODEL 103600010
SERIAL NO. 6110H



INTERMODULATION REDUCTION DEVICE
MODEL 103600010
SERIAL NO. 6110H



VHF DISTRIBUTED CIRCULATOR
MODEL 100101775 SERIAL NO 6111H
PORT 1 TO PORT 2

FREQ-MHZ	LOSS-DB FORWARD	VSWR FORWARD	ISOL-DB REVERSE	VSWR REVERSE
118.000	.30	1.38	21.99	1.31
118.500	.30	1.38	21.87	1.31
119.000	.31	1.38	21.70	1.32
119.500	.32	1.38	21.55	1.32
120.000	.32	1.38	21.36	1.32
120.500	.34	1.38	21.18	1.32
121.000	.32	1.38	21.02	1.32
121.500	.33	1.37	20.84	1.32
122.000	.34	1.37	20.68	1.32
122.500	.34	1.37	20.53	1.32
123.000	.36	1.36	20.40	1.32
123.500	.37	1.36	20.25	1.32
124.000	.35	1.35	20.14	1.32
124.500	.36	1.35	20.04	1.31
125.000	.35	1.34	19.96	1.31
125.500	.35	1.33	19.89	1.30
126.000	.34	1.32	19.84	1.30
126.500	.34	1.32	19.81	1.29
127.000	.34	1.31	19.77	1.29
127.500	.34	1.30	19.75	1.28
128.000	.33	1.29	19.78	1.27
128.500	.32	1.28	19.79	1.26
129.000	.32	1.27	19.83	1.25
129.500	.31	1.25	19.88	1.24
130.000	.31	1.24	19.94	1.23
130.500	.30	1.23	20.03	1.23
131.000	.29	1.22	20.10	1.21
131.500	.28	1.20	20.22	1.21
132.000	.28	1.19	20.35	1.20
132.500	.27	1.18	20.51	1.18
133.000	.27	1.17	20.66	1.17
133.500	.26	1.15	20.83	1.16
134.000	.26	1.14	21.01	1.15
134.500	.26	1.13	21.22	1.14
135.000	.24	1.11	21.44	1.13
135.500	.24	1.10	21.64	1.12
136.000	.24	1.08	21.98	1.11

VHF DISTRIBUTED CIRCULATOR
MODEL [illegible] SERIAL NO [illegible]
PORT [illegible] TO PORT [illegible]

FREQ-MHZ	LOSS-DB FORWARD	VSWR FORWARD	ISOL-DB REVERSE	VSWR REVERSE
118.000	.24	1.27	18.24	1.14
118.500	.27	[illegible]	18.29	1.15
119.000	.24	[illegible]	[illegible]	[illegible]
119.500	.26	1.29	[illegible]	[illegible]
120.000	.25	1.29	18.14	[illegible]
120.500	.27	1.30	[illegible]	1.17
121.000	.25	1.30	18.14	1.17
121.500	.24	[illegible]	18.15	[illegible]
122.000	.27	1.29	18.17	[illegible]
122.500	.28	1.28	18.20	1.19
123.000	.28	1.30	[illegible]	1.19
123.500	.29	[illegible]	[illegible]	1.19
124.000	[illegible]	1.29	[illegible]	1.19
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
127.500	.31	[illegible]	[illegible]	1.19
128.000	.31	1.25	[illegible]	1.19
128.500	.31	1.25	[illegible]	1.19
129.000	[illegible]	1.24	[illegible]	1.19
129.500	[illegible]	1.21	[illegible]	1.19
130.000	.30	1.21	[illegible]	[illegible]
130.500	[illegible]	1.21	[illegible]	1.19
131.000	.30	1.20	[illegible]	1.18
131.500	[illegible]	[illegible]	[illegible]	1.17
132.000	.29	[illegible]	[illegible]	[illegible]
132.500	[illegible]	1.17	[illegible]	[illegible]
[illegible]	.27	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

VHF DISTRIBUTED CIRCULATOR
MODEL 100101775 SERIAL NO 6111H
PORT 3 TO PORT 1

FREQ-MHZ	LOSS-DB FORWARD	VSWR FORWARD	ISOL-DB REVERSE	VSWR REVERSE
118.000	.23	1.11	17.76	1.33
118.500	.24	1.11	17.72	1.33
119.000	.25	1.12	17.70	1.33
119.500	.25	1.12	17.68	1.33
120.000	.25	1.13	17.69	1.32
120.500	.26	1.13	17.69	1.32
121.000	.24	1.14	17.73	1.32
121.500	.26	1.14	17.77	1.32
122.000	.27	1.15	17.82	1.31
122.500	.27	1.15	17.90	1.31
123.000	.28	1.15	18.00	1.30
123.500	.29	1.16	18.11	1.30
124.000	.29	1.16	18.23	1.29
124.500	.28	1.16	18.36	1.29
125.000	.29	1.16	18.52	1.28
125.500	.30	1.16	18.69	1.27
126.000	.30	1.16	18.90	1.26
126.500	.29	1.16	19.11	1.25
127.000	.30	1.16	19.36	1.24
127.500	.29	1.16	19.61	1.23
128.000	.29	1.15	19.89	1.22
128.500	.28	1.15	20.19	1.21
129.000	.28	1.15	20.52	1.20
129.500	.28	1.14	20.87	1.19
130.000	.28	1.14	21.25	1.18
130.500	.28	1.14	21.66	1.17
131.000	.27	1.14	22.08	1.16
131.500	.27	1.13	22.54	1.14
132.000	.26	1.13	23.00	1.13
132.500	.26	1.12	23.47	1.12
133.000	.26	1.12	23.96	1.11
133.500	.25	1.12	24.40	1.10
134.000	.24	1.11	24.81	1.09
134.500	.25	1.11	25.15	1.08
135.000	.26	1.11	25.42	1.07
135.500	.27	1.11	25.52	1.07
[illegible]	.27	1.11	25.41	[illegible]

Appendix B. Measurement Data for Intermodulation Products

This appendix contains the IMP data obtained on both the Intermodulation Reduction Device and the VHF Distributed Circulator. Tables 1 and 2 display the IMP data for the Intermodulation Reduction Device, taken at the manufacturer's facility. The three bands referred to in the tables are the three frequency sets used to test the IRD. These frequency sets are as follows:

Low Band:	Forward Signal	122 MHz
	Reverse Signal	118 MHz
	IMP	126 MHz
Mid Band:	Forward Signal	125 MHz
	Reverse Signal	129 MHz
	IMP	121 MHz
High Band:	Forward Signal	132 MHz
	Reverse Signal	136 MHz
	IMP	128 MHz

Table 3 shows test data for the VHF Distributed Circulator under simiiar test conditions. Since the Distributed Circulator was not temperature-compensated to operate under temperature extremes, it was tested only at room temperature (+22°C). All data in tables 1, 2 and 3 was taken using a forward signal (f_1) of 50 watts, CW, and a reverse signal of

0.1 watt, CW. Table 4 provides additional data for the Distributed Circulator, showing the effects of varying the power levels and the spacing in frequency of the two signals.

The test set used to make these measurements is shown in figure 12.

Intermodulation Product Levels (P_{fwd}=50 watt; P_{rev}=0.1 watt)

Serial No. of IRD	-10°C Low Band	-10°C Mid Band	-10°C High Band	+22°C Low Band	+22°C Mid Band	+22°C High Band	+60°C Low Band	+60°C Mid Band	+60°C High Band
6099H	-42.6	-40.1	-40.1	-40.9	-40.6	-39.7	-44.2	-42.6	-38.8
6100H	-41.4	-38.6	-39.2	-38.9	-38.0	-42.5	-42.7	-39.8	-39.3
6101H	-45.4	-44.5	-41.8	-44.9	-42.3	-37.0	-48.4	-45.8	-37.1
6102H	-41.9	-38.7	-37.1	-42.4	-35.8	-37.6	-42.6	-38.7	-35.7
6103H	-41.4	-38.6	-44.5	-41.4	-39.4	-43.6	-42.1	-40.5	-45.3
6104H	-44.8	-38.8	-39.3	-42.4	-39.3	-41.5	-43.2	-39.7	-43.5
6105H	-41.6	-40.5	-38.1	-40.4	-41.8	-38.1	-37.7	-35.6	-45.3
6106H	-39.7	-38.4	-45.3	-38.9	-37.1	-43.5	-42.5	-40.2	-38.1
6107H	-38.4	-39.1	-44.3	-37.7	-40.0	-42.8	-38.9	-41.0	-43.2
6108H	-40.6	-38.6	-40.5	-39.6	-37.6	-41.3	-42.2	-42.2	-37.0
6109H	-37.4	-33.3	-37.8	-44.9	-40.6	-51.3	-50.0	-43.3	-49.3
6110H	-40.2	-41.0	-43.6	-40.0	-41.6	-42.1	-40.5	-43.3	-42.5

Note: All IMP levels are in dBm

Table 1. Strong IMP for 50 Watts of Forward Power (IRD)

Intermodulation Product Levels (P_{fwd}=10 watt from IRD; P_{rev}=0.1 watt)

Serial No. of IRD	-10°C Low Band	-10°C Mid Band	-10°C High Band	+22°C Low Band	+22°C Mid Band	+22°C High Band	+60°C Low Band	+60°C Mid Band	+60°C High Band
6099H	-44.6	-44.8	-42.8	-42.9	-44.7	-42.8	-47.4	-45.8	-42.0
6100H	-45.4	-42.7	-41.7	-42.4	-41.3	-46.8	-45.2	-42.6	-42.3
6101H	-43.7	-44.6	-46.4	-45.4	-45.1	-41.0	-60.0	-48.8	-40.8
6102H	-44.9	-42.0	-40.8	-44.6	-39.7	-41.8	-44.9	-41.[illegible]	-38.8
6103H	-44.9	-43.4	-48.3	-44.2	-43.1	-47.3	-44.1	-44.4	-51.3
6104H	-46.4	-41.6	-41.9	-44.2	-42.6	-44.5	-45.4	-43.0	-45.8
6105H	-43.4	-43.3	-40.7	-45.0	-43.5	-41.4	-40.6	-39.6	-48.3
6106H	-42.4	-41.3	-44.5	-41.2	-40.6	-46.8	-44.0	-42.0	-40.5
6107H	-41.9	-42.4	-47.3	-40.4	-42.3	-46.3	-42.1	-44.3	-43.1
6108H	-42.9	-40.8	-43.1	-42.2	-41.8	-42.8	-44.9	-44.3	-40.1
6109H	-40.2	-38.6	-41.7	-49.4	-44.8	-53.3	-60.0	-49.8	-55.3
6110H	-42.4	-44.6	-49.3	-42.2	-44.8	-44.8	-43.6	-46.8	-43.5

Note: All IMP levels are in dBm

Table 2. Strong IMP for 10 Watts of Forward Power (IRD)

VHF Distributed Circulator IMP Data

Temp	f_1 (MHz)	f_2 (MHz)	f_{IM} (MHz)	Strong IMP 50W fwd	Strong IMP 10W to load
+22°C	122	118	[illegible]	-43.8	-49.4
	125	129	[illegible]	-42.2	-45.8
	132	136	128	-42.1	-39.1

Note: All IMP levels are in dBm.

Pf_1 = +47 dBm; Pf_2 = +20 dBm

Table 3. Strong IMP for Distributed Circulator (Contractors Data)

VHF Distributed Circulator IMP Data

Temp	Pf_1 to load: Watts	Pf_1 to load: dBm	Pf_2 (Pf_1-20 dB): Watts	Pf_2 (Pf_1-20 dB): dBm	P_{IM} (dBm) for f_1 = 122 MHz, f_2 = 126 MHz, f_{IM} = 118 MHz	P_{IM} (dBm) for f_1 = 126 MHz, f_2 = 134 MHz, f_{IM} = 118 MHz
+22°C	75	+48.5	0.75	+28.5	-38	-42
	50	+47	0.5	+27	-39	-44
	25	+44	0.25	+24	-41	-46
	10	+40	0.1	+20	-44	-50

Table 4. Strong IMP for Distributed Circulator (RADC Data)

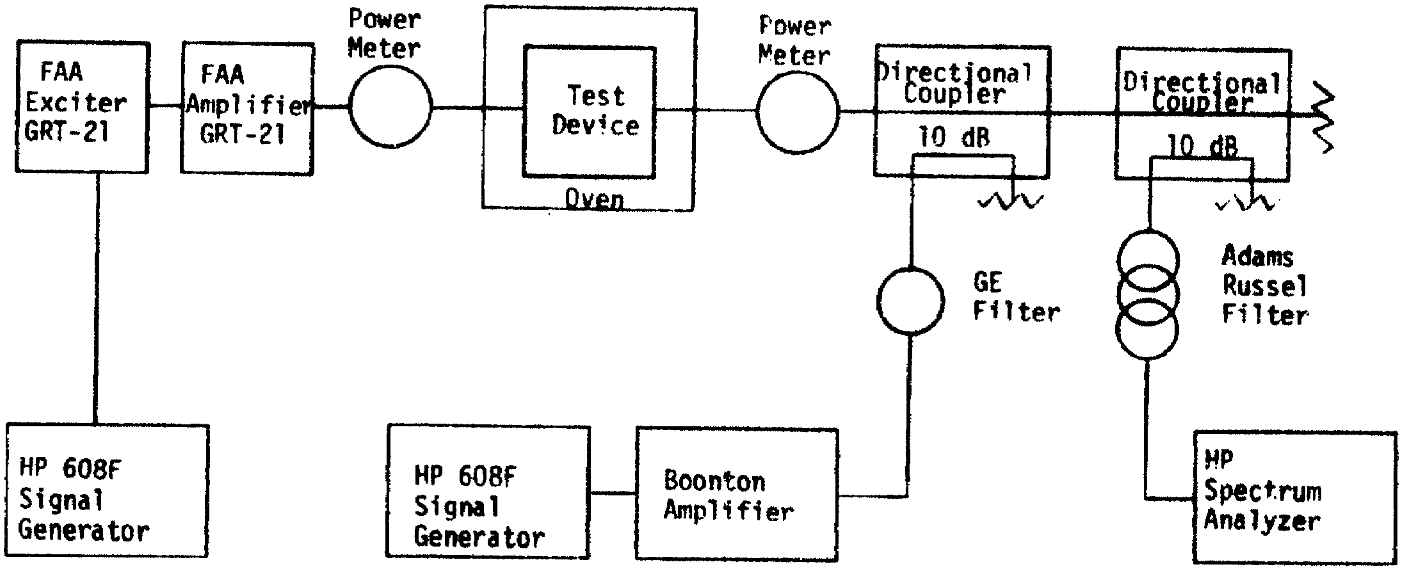


Figure 12. The IMP Test Set

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